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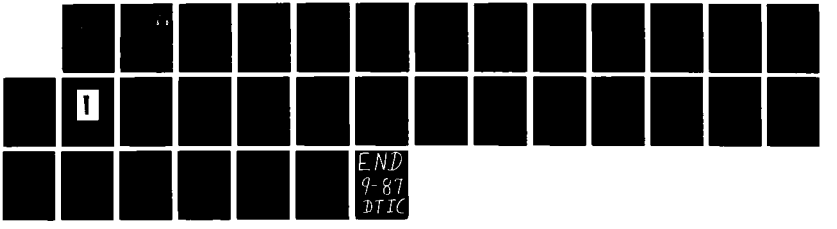

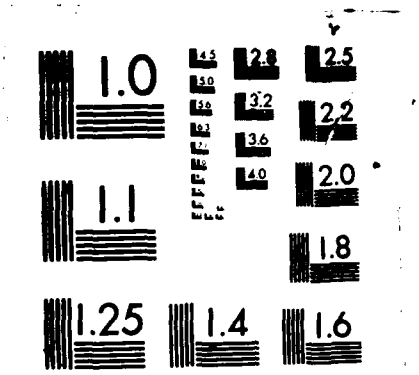

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SURGICAL TOOTH IMPLANTS, COMBAT AND FIELD

ANNUAL REPORT

CRAIG R. HASSLER

July 15, 1984

Supported by

U. S. ARMY MEDICAL RESEARCH AND DEVELOPMENT COMMAND
Fort Detrick, Frederick, Maryland 21701-5012

Contract No. DAMD17-82-C-2020

BATTELLE
Columbus Division
505 King Avenue
Columbus, Ohio 43201-2693

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This Annual Report summarizes progress to date on a long-term implant study of a serrated ceramic dental implant designed for fresh extraction sites. The baboon study was successfully completed last year. Clinical studies are presently continuing. The implants are single tooth rectangular design with serrations arranged for maximal stress distribution of occlusal loads. A three-piece design is used to minimize stresses upon the root portion during the bone ingrowth phase. The serrated root portion is produced from high purity dense aluminum oxide (Al_2O_3). The upper two parts of the implant, post and core and crown, are conventional metal materials. A series of graded dental implants have been produced to provide an interference fit in any fresh extraction site. The long-term implant studies in baboons were terminated late last year after an average residence time of implantation of 5.25 years in 5 baboons. The longest implant time in this baboon series was 7.71 years. In summary, 88 percent of the implants in baboons survived the

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initial ingrowth phase. The ingrowth failures were early implant attempts suggesting technique or operative experience may be a contributing factor. Thirty-eight implants were rigidly retained by bone ingrowth. Of these implants 63 percent or 24 implants were complete functional units at time of necropsy. Implants not completed at experimental termination included implant fractures, lost crowns, and implants that were never restored. Only one of the 38 implants became loose after initial ingrowth. Consequently 37 of 38 or 97 percent of the implants which became rigidly fixed in bone could have successfully functioned if extenuating circumstances had not prevented or prematurely shortened the restoration of these implants. Histologic analyses of the bone implant interface has been performed at various time intervals. An increase in bone density appears to be associated with the early functional stage of implant life. Later, well organized bone mixed with some connective tissue is typically observed totally filling the serrations. Numerous areas of apposition between bone and ceramic are observed. Alveolar bone height appears to be well maintained in all implants throughout the experimental period. Periodic radiographic analyses of dental implants verify this observation. Gross and microscopic pathologic analyses were performed on selected organs of all animals in the study. No implant-related lesions were observed. The pathologic changes recorded were interpreted as representing spontaneous, clinically insignificant disease from the effect of old age in the majority of cases. The pathologist's evaluation was that there was no definitive evidence of any adverse effects related to the chronic implantation of ceramic teeth in the baboon.

Samples were collected from 15 organ or tissue sites and assayed for aluminum concentration via atomic absorption spectrophotometry. Increases in aluminum concentration were noted in the lungs, regional lymph nodes, gingiva, tongue, and masseter muscle. When compared to a similar study where titanium alloy orthopaedic implants containing aluminum (Ti-6AL-4VA) were studied, similar increases in the lung and lymph node concentrations were observed. Increases in muscle, tongue, and gingiva aluminum ion concentrations can be explained by the close proximity between the implant and the tissue sample. In the dental implant animals, there was no noted increase in aluminum concentration in the brain. Adequate animal data were not available from this study to ascertain the release rate of aluminum oxide from the dental implant sites.

Human studies to date have been divided into three different experimental groups:

- Group I - freestanding implants placed slightly above the alveolar ridge at the time of surgery
- Group II - implants stabilized by splinting to adjacent teeth
- Group III - implants placed below or flush with the alveolar crest.

In Group I of the human studies, 25 patients were implanted with mandibular, premolar, or molar site implants. Eight implants or 32 percent remain. The average group implant time is 5.12 years. The average time to failure for restored implants was 2.06 years. However, only three of these patients have been available for recent followup. Therefore, these numbers should be viewed cautiously. The Group II tooth implants were splinted. Six patients received implants in the posterior mandibular area. Sixty-seven percent of these implants remain intact. The average implant time is 3.73 years. The average time for failure was 1 year. The average implant time for restored implants is 1.75 years. Group III implants were placed flush with or below the alveolar crest. Twenty-nine patients

19. Abstract (Cont'd.)

were implanted with posterior mandibular or anterior maxillary area implants. Eighteen or 62 percent remain intact. The average implant time is 1.79 years. The average failure time of restored implants was 0.89 years.

The data indicated some advantage of the alternative techniques of splinting and/or deeper initial placement since a higher long-term success rate was evident. We suggest that the additional isolation from mechanical stresses provided by the Group II and Group III techniques appear to have made a significant difference in the maintenance of stability. However, the experiment time of Group II and especially Group III implants is relatively short compared to Group I. It is premature to prejudge the results. Two important observations should be made with this implant system. First, the system is based upon a series of rectangular implants specifically designed to be placed in fresh extraction sites. This particular design restriction is in keeping with the military design to utilize basically the fresh extraction scenario for immediately replacing traumatically injured dentition. However, the negative effects of this design constraint are that a rectangular socket must be fashioned to accept the implant. Fashioning of a tapered rectangular socket is, under the best conditions, a more difficult task than preparing a hole of circular cross-section. Also, immediate intimate bone contact cannot be obtained as is possible with a circular device. It is our contention that much higher success of this implant technology can be obtained in circular cross-section roots for edentulous cases. However, the present rectangular system appears successful for its intended fresh extraction site application.

QUALITY ASSURANCE STATEMENT

This study was inspected by the Quality Assurance Unit and reports were submitted to management and the principal investigator as follows:

Phase	Date
Clinical observations, pictures, X-rays, blood collection, body weights, flossing and brushing of teeth.	3/28/83
Necropsy	4/7/83
Review of annual report	8/9/83, 3/6/85
Reports to principal investigator and management	8/9/83, 3/6/85

To the best of my knowledge, the methods described were the methods followed and the data presented accurately represent data generated during the study.

Richard A. Shamb for

Ramona Mayer, Director
Quality Assurance Unit
Biological Sciences Department

SURGICAL TOOTH IMPLANTS, COMBAT AND FIELD

by

Craig R. Hassler

SUMMARY

This Annual Report summarizes progress to date on a long term implant study of a serrated ceramic dental implant designed for fresh extraction sites. The baboon study was successfully completed last year. Clinical studies are presently continuing. The implants are single tooth rectangular design with serrations arranged for maximal stress distribution of occlusal loads. A three-piece design is used to minimize stresses upon the root portion during the bone ingrowth phase. The serrated root portion is produced from high purity dense aluminum oxide (Al_2O_3). The upper two parts of the implant, post and core and crown, are conventional metal materials. A series of graded dental implants have been produced to provide an interference fit in any fresh extraction site. The long term implant studies in baboons were terminated last year after an average residence time of implantation of 5.25 years in 5 baboons. The longest implant time in this baboon series was 7.71 years. In summary, 88 percent of the implants in baboons survived the initial ingrowth phase. The ingrowth failures were early implant attempts suggesting technique or operative experience may be a contributing factor. Thirty-eight implants were rigidly retained by bone ingrowth. Of these implants 63 percent or 24 implants were complete functional units at time of necropsy. Implants not completed at experimental termination included implant fractures, lost crowns, and implants that were never restored. Only one of the 38 implants became loose after initial ingrowth. Consequently, 37 of 38 or 97 percent of the implants which became rigidly fixed in bone could have successfully functioned if extenuating circumstances had not prevented or prematurely shortened the restoration of these implants. Histologic analyses of the bone implant interface has been performed at various time intervals.

An increase in bone density appears to be associated with the early functional stage of implant life. Later, well organized bone mixed with some connective tissue is typically observed totally filling the serrations. Numerous areas of apposition between bone and ceramic are observed. Alveolar bone height appears to be well maintained in all implants throughout the experimental period. Periodic radiographic analyses of dental implants verify this observation. Gross and microscopic pathologic analyses were performed on selected organs of all animals in the study. No implant related lesions were observed. The pathologic changes recorded were interpreted as representing spontaneous, clinically insignificant disease from the effect of old age in the majority of cases. The pathologist's evaluation was that there was no definitive evidence of any adverse effects related to the chronic implantation of ceramic teeth in the baboon.

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The data indicated some advantage of the alternative techniques of splinting and/or deeper initial placement since a higher long term success rate was evident. We suggest that the additional isolation from mechanical stresses provided by the Group II and Group III techniques appear to have made a significant difference in the maintenance of stability. However, the experiment time of Group II and especially Group III implants is relatively short compared to Group I. It is premature to prejudge the results. Two important observations should be made with this implant system. First, the system is based upon a series of rectangular implants specifically designed to be placed in fresh extraction sites. This particular design restriction is in keeping with the military desire to utilize basically the fresh extraction scenario for immediately replacing traumatically injured dentition. However, the negative effects of this design constraint are that a rectangular socket must be fashioned to accept the implant. Fashioning of a tapered rectangular socket is, under the best of conditions, a more difficult task than preparing a hole of circular cross-section. Also, immediate intimate bone contact cannot be obtained as is possible with a circular device. It is our contention that much higher success of this implant technology can be obtained in circular cross-section roots for edentulous cases. However, the present

rectangular system appears successful for its intended fresh extraction site application.

FOREWORD

This study has been conducted at Battelle's Columbus Laboratories utilizing the staff and resources of the Toxicology and Health Sciences Section and the Ceramics Section. The clinical portion of this study has been conducted at The Ohio State University College of Dentistry.

This is the fourteenth report of progress under Contract No. DAMD17-82-C-2020, "Surgical Tooth Implants, Combat and Field". The Principal Investigator for this research was Dr. Craig R. Hassler. Ceramics research was directed by Ms. Carole Markhoff. The human studies have been under the direction of Dr. Mark Brose in the clinical facilities of The Ohio State University College of Dentistry. Clinical research was conducted under a protocol approved by The Ohio State University Human Subjects Committee. This research has been performed in accordance with an investigational device exemption obtained from the FDA.

Citations of commercial organizations and trade names in this report do not constitute an official Department of the Army endorsement or approval of the products or services of these organizations.

In conducting the research described in this report, the investigator(s) adhered to the "Guide for the Care and Use of Laboratory Animals," prepared by the Committee on Care and Use of Laboratory Animals of the Institute of Laboratory Animal Resources, National Research Council (DHEW Publication No. (NIH) 78-23, Revised 1978).

For the protection of human subjects, the investigator(s) have adhered to policies of applicable Federal Law 45CFR46.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

BACKGROUND

Dental implants may play an important role in the maxillofacial repair tasks which are of great interest to the U.S. Army Medical Research and Development Command. In the last several years, a new generation of dental implants has evolved. These devices are designed to be rigidly affixed by bone ingrowth and provide minimization of stress usually being serrations[1,4] or pores.[5,6] Generally, these implants are designed as single freestanding prostheses. Several biocompatible materials have been utilized including plastics,[7] metallics,[6] and ceramics.[1,2,3, 8-18,22-24,26-29] Our laboratory has specialized by using alumina (Al_2O_3) ceramics incorporating a serrated rectangular design. These implants are specifically designed for use in fresh extraction sites. In the past 13 years we have developed a combination of material, design, and technique components which appear promising. It should be noted that all three components (design, material, and technique) are of importance if an implant system is to be successful. Failure of any of the three components can be detrimental. A serrated ceramic implant system based upon these principles is under test in our laboratories. Implant experiments in animals was completed after 8 years. On the strength of the animal experiments, a clinical study was undertaken to evaluate how much of the technology was relevant to the human situation.

The lower portion of our three-piece implants are produced from alumina (Al_2O_3) (Figure 1). This portion has large serrations into which bone ingrowth has been demonstrated.[4] The implant illustrated in Figure 1 has smaller serrations at the crown end of the root to increase the strength of smaller sized roots in these critical areas. The upper two portions of the implant: post and core and crown, are cemented after ingrowth to allow function. The three-piece design allows minimization of occlusal stresses and strains on the implant to facilitate bone ingrowth. An analogous situation is seen in the healing of long bone. It is assumed that, as in long bone, an orderly transition through a sequence of gradually stiffer bone materials proceeds (hematoma → connective tissue → woven bone → compact bone). The maximal strain which any of these tissues can withstand must not be exceeded if healing is to proceed to completion.[21] Consequently, strain upon the

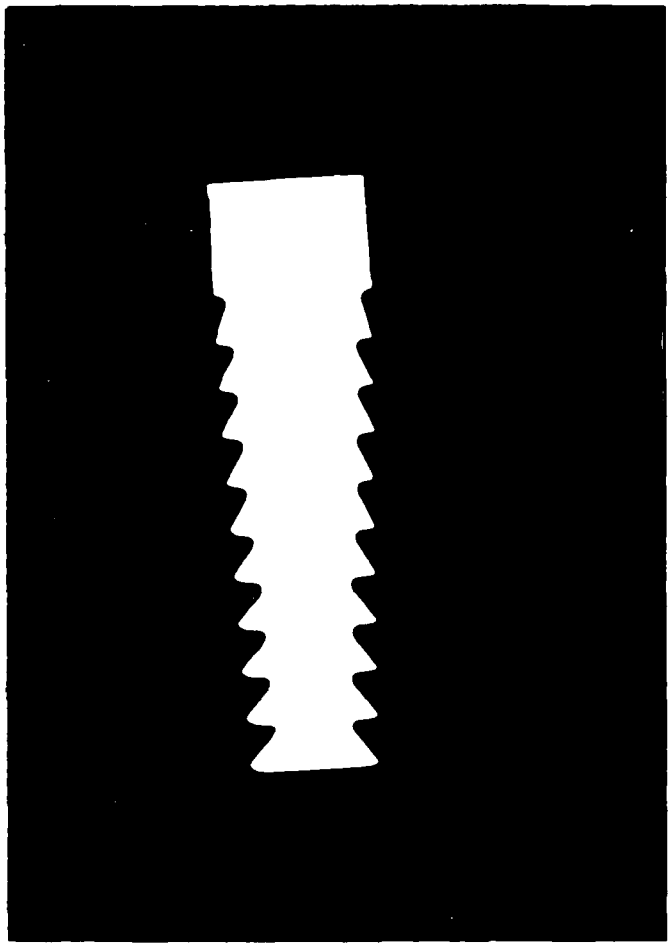

FIGURE 1. SERRATED ALUMINUM OXIDE DENTAL IMPLANT

This photograph shows a rectangular root with smaller serrations at the top for increased strength. Not visible is the post hole in the center of the implant. A prefabricated post and core is cemented into the hole. A clinical crown is then cemented to the post and core.

implant-bone interface must be minimized early in the healing process if bone formation is to occur. Once the implant is stabilized by ingrowth, the large implant surface area at right angles to the principal load axis of the implant is intended to maintain bone stresses below a level which produces resorption of bone. Attempts to quantify these stresses have been made in this laboratory.[9] This information is not specifically for alveolar bone; however, it serves as a guide in an area where no direct information is available. Finite element analyses performed on this design,[30] indicated that stresses in the bone were below design maximum for typical occlusal loads. The histologic data collected during this project[2] show that bone can be maintained for extended periods, in intimate contact with a functional implant. This observation supports the hypothesis that the design has limited the stresses at the interface to acceptable levels.

The above mentioned parameters, unique to this design, are the serrations and three-piece construction. These are the two major determinants for design success. A secondary design parameter which has proven useful is the availability of various size implants. A size gradation allows optimal fit into the available site. Numerous sizes have been produced for the clinical studies. In practice, several of these sizes are not used, but they are available when required. Both rectangular and elliptical implants were used in the baboons. However, the rectangular shape appeared to provide a better initial fit in a fresh extraction site. Consequently, this design is being used exclusively in human clinical trials.

The shape and size flexibility of the rectangular design is especially crucial when placing implants in fresh extraction sites. A circular implant will rarely provide adequate initial stability in a fresh extraction site. Furthermore, implant size is limited by the buccal-lingual dimension with a circular design. Disadvantages to the rectangular design are that more operator skill is required to initially place the implant than would be required with a circular implant. Also, the design prevents the immediate intimate contact between bone and implant that can be obtained with a circular design that is "threaded" into bone.

The method of producing roots by contour grinding, on a computer controlled milling machine, has allowed for flexibility not only in size, but in other design changes. In a research protocol, this ease of flexibility has been an asset and will continue to be our method of root manufacture.

METHODS

Fabrication of Tooth Roots

No implants were fabricated during this project year since adequate implants were on hand to complete the proposed clinical studies. However, a brief description of the techniques used is included here. The powder used for fabrication is Reynolds Aluminum Company's RC-HP-DBM. This is a high purity, dry ball milled powder having a median partical size of approximately 0.5 microns. The methods for production of the tooth roots have been reported previously.[27,28] The processing procedure used is as follows:

(1) Hydrostatic pressing granulated material at 50,000 psi to form preform rods nominally 125 mm long by 14 mm diameter
(2) Bisque firing preform rods at 1120°C for 2 hours
(3) Contour grinding tooth roots
(4) Hand finishing tooth roots
(5) Final sintering at 1540°C for 1 hour.

A quality assurance program is utilized on all roots destined for clinical trials. The details of this program have been published in our previous reports.[27,28] This program consists of:

(1) A method of traceability which allows each root to be identified as to raw material, size, and time of manufacture.
(2) Manufacture of test bars, which are produced for each batch of roots. Presently flexural strengths averaging 70,000 psi are being obtained.
(3) Microscopic examinations of each root by both transmitted and reflected light.
(4) Wet density measurements of representative implants from each group.

Baboon Implant Procedures

No animal implants were performed this year. The procedures used in the baboon are briefly outlined below. Typically, following extraction, the

tooth socket was shaped using a bone burr. The socket was formed by a continual fitting procedure. The root was firmly tapped into the alveolar bone until flush with the bone. The root was given no further attention, however, the animal received prophylactic antibiotics immediately post-surgery and a soft diet for two weeks. The root implant site was observed periodically for three months. Radiographic examination and manual palpation indicated if the root was adequately stable for reconstruction.

Restoration of the implants was facilitated by prefabrication of a gold post and core prior to implantation. Following adequate stabilization by bone ingrowth into the serrations (at approximately three months), the post and core was cemented into place and impressions were taken. A gold crown was fabricated and cemented into place. Care was taken to provide correct occlusion. The implants were periodically examined and documented by radiographs and photographs.

Additional Animal Techniques

Clinical chemistry, hematology and parasite analyses were continued periodically and at experiment termination. One half of the animal colony (animals 469, 709, and 712) were scaled, flossed and then brushed for three minutes with a two percent solution of chlorohexidine gluconate four times prior to necropsy. (The teeth were scaled only initially.) The treatments were at approximately weekly intervals.(32)

For histomorphometric analysis of bone rates, all animals were tetracycline double labeled in a 2-7-2-7 pattern prior to necropsy.(33) Analyses of these data are now underway.

Human Implant Procedures

Rectangular implants were placed in edentulous, or fresh extraction sites. Roots were placed where they would function as single, freestanding implants when reconstructed. Under local anesthesia, implant sites were prepared using bone burrs placed in a low-speed contra-angle air turbine handpiece with sterile saline cooling. A continual fitting procedure was used.

Final placement of the implant was via tapping with a mallet to provide a stable interference fit. The root implant site was observed visually and radiographically throughout the study. Normally a gold post and core was prefabricated for each implant. The patients were observed periodically until the implant was rigid or exhibited minimal motion. At that time, the post and core was cemented and a clinical crown fashioned. Periodic examination of the patient continues following reconstruction. All clinical studies are performed at The Ohio State University College of Dentistry, in compliance with a protocol approved by The Ohio State University Human Subjects Committee and the FDA Bureau of Medical Devices.

Three variations of implant technique have been employed: in the first group, implants were surgically placed so that the uppermost serration was just covered by the crest of the alveolar ridge. Consequently, about 3 mm of implant was left protruding above the ridge. The first 25 patients' implants were implanted in this fashion.

A second group of 6 patients' implants were prepared with integral post and cores. The implants were partially isolated from occlusal loads by orthodontic stay wires attached to adjacent dentition and a methacrylate resin cap over the top of the implant.

A third group of 29 patients was prepared in which the top of the root was placed flush with the alveolar crest. Whenever possible, a muco-periosteal flap was placed over the top of the implant. Both anterior maxillary and posterior mandibular sites were included in this third group.

RESULTS

Animal Studies

Summary Analysis of Baboon Implant Data

For the purpose of this analysis, all implants have been classified according to their "final" status at time of death or necropsy. Some implants underwent a complicated course involving several different procedures. This

analysis is intended as a "worst case" analysis where each implant is categorized according to its least favorable outcome. This analysis includes all implants placed in the 9 animals retained at Battelle for the long term dental implant study.

Forty-three attempts were made to place implants. Thirty-eight, or 88 percent of the implants survived the initial ingrowth phase. All of these ingrowth failures were early implant attempts (prior to 1977). Three of the five failures occurred in one animal. This animal was successfully implanted, suggesting that technique improvements or operator experience may be failure contributing factors. Suspected failure modes include: fracture of the buccal plate, and placing the implants too high relative to the alveolar crest.

Of the 38 implants which were retained, 24 or 63 percent were totally functional and complete implant units at necropsy or animal death. The 14 implants not complete at experiment termination were distributed in the following manner:

- 8 implants fractured while in service
- 1 implant lost its post and core and crown
- 1 implant was fractured during an attempted removal
- 4 were never restored.

These implants were analyzed in the following manner; all fractured roots were from the same processing batch. No implants manufactured either before or after that particular batch have ever fractured. Consequently, poor material quality is suspected. These early implants were not put through a quality assurance program as is the practice with implants prepared for clinical study. The implants that did fail experienced an average of 3.27 years $\pm$ 1.49 years before failure. Extreme crown wear seen on all baboon dental implants indicated that the animals severely stressed the devices. However, the actual contribution of severe treatment to implant fracture cannot be determined.

The post and core and crown loss is suspected to be due to faulty zinc oxyphosphate cement, and probably not related to a difficulty with the implant per se. Suspected cement failures were seen in other implants which were recemented and are classified elsewhere. For example, area 18 in animal

469 lost its crown after three years. The implant remained in function via the post and core until two months before necropsy when the implant fractured. This implant is counted as a fracture failure in this analysis. A similar example was seen in animal 713 area 20. A crown was lost due to cement failure after two years. The crown was recemented. However, the implant eventually fractured and was categorized as a fracture loss. A total of three implants exhibited cement failures, were reconstructed and went on to eventually fail due to fracture.

One implant in animal 712, area 19 presented an interesting case history. This implant never became stable. After 16 weeks removal was attempted, at which time the implant fractured. The remaining root, now below alveolar crest, became rigidly fixed in the bone and remained. This implant compounds the analysis since technically it is a loss, but still remained in the animal. Consequently, the implant was placed in a unique category. A similar incident was noted in animal B, area 29. The implant was placed in function earlier than usual. Normally at least 90 days is permitted to elapse, but in this case, only 68 days elapsed before reconstruction was undertaken. The implant loosened progressively. Twice, in the next 2.25 years, crown height was reduced to minimize function on the implant, but the implant remained mobile. Eventually, after four years, the implant fractured. The root segment of the implant, now totally removed from any function, became rigidly fixed in the bone and remained so. These two cases suggest that a mobile root can eventually stabilize, but only in the absence of external stresses.

The four implants, never restored, were placed late in the program to train new clinicians for the clinical program. The residence time of these roots was too short (with one exception) to judge whether they would have been successful or not.

The 24 implants, termed totally successful, experienced an average implant residence time of 5.26 years $\pm$ 1.49 years. It is significant in that, with one exception, all baboon implants which became rigidly implanted remained rigidly fixed. A very optimistic analysis could state a 33 out of 34, or 97 percent success rate for stabilized roots, if various mechanical failure modes such as implant fracture and cement failure are discounted. On

the other hand a pessimistic analysis of the data could state that only 24 of the 43 roots (56 percent) were totally successful. The percentage could be even further reduced if crowns with extensive wear are considered failures. Obviously, the true success of the implant system is between the above stated percentages. The perception of success depends upon the analysis criteria employed. It is most important to indicate that the data strongly supports the hypothesis that a dental implant of this design can become rigidly fixed in bone and satisfactorily distribute the occlusal stresses on an extended basis.

Histopathology Report

Analysis of tissue collected at gross necropsy was performed by the U.S. Army Pathology Laboratory under the direction of James B. Moe, D.V.M., Ph.D., Director of the Division of Pathology. Tissues were microscopically analyzed. Pathology narrative stated that a variety of pathologic lesions and tissue changes were observed in these baboons. Essentially all changes were interpreted as representing spontaneous clinically insignificant disease or effects of old age in the majority of cases. An interesting finding was the presence of nodular collections of hydroplastic acidophil cells in the anterior portion of the pituitary, a lesion which is not often observed in other species. The significance of this hydroplastic lesion is unknown. However, it is doubtful that this or any other lesion recorded reflected an adverse effect of chronic implantation of the ceramic teeth. Further special pituitary studies of the pituitary tissue from these baboons were underway at the time of this report to better resolve the significance and the change observed. In summary, Dr. Moe concluded there was no definitive evidence of an adverse systemic effect of chronic implantation of ceramic teeth in the baboons tissue. Complete histopathologic analysis is available on one other animal which had died earlier. A complete report of this early death is included in the 13th Report[30]. The pathologist's analysis in this case was that the animal died of septicemia, the point of origin of infection not ascertained.

Aluminum Analyses

As with any implanted material there is always concern for the ultimate fate of that material in the body. To that end, tissue samples were collected from baboons at the time of scheduled necropsy. Elemental analyses for aluminum were performed. Table 1 indicates the 15 tissues that were analyzed for aluminum. Since no unimplanted control animals were included in our colony, two animals of approximately the same age housed under similar conditions were obtained from an unrelated experiment performed at The Ohio State University. The samples were analyzed by Dr. James L. Woodman at Rush Presbyterian St. Lukes Medical Center utilizing a Perken-Elmer model 4000 spectrophotometer with a HG8-400 graphite furnance. The techniques have been previously published.(31)

The aluminum oxide dental implant animals showed elevations of tissue aluminum concentration especially in the lungs, regional lymph nodes, gingiva, tongue and masseter muscle (see Table 1). Also included in Table 1 are comparative values reported by Woodman(31) for a similar long term metallic ion analysis study in baboons. His study used Ti-6AL-4VA samples. Thus, the source of aluminum ion in his study was the titanium alloy. The data included from his publication is for animals from his study group with implant durations similar to those animals in our study group. It is of interest to note similar aluminum ion increases in the two studies from the aluminum containing titanium long bone implants and the aluminum oxide dental implants. Control tissue concentrations are the same order of magnitude for the control animals from both studies. In the dental implant study, the muscle harvested was the masseter, in the vicinity of the dental implant. In the case of the Woodman(31) titanium study, muscle was harvested from skeletal muscle adjacent to the implant. There is almost a two-fold aluminum concentration in the muscle as compared to controls.

In dental implant animals tongue and gingiva aluminum concentrations were elevated. These tissues were in close proximity to the dental implants. Decreases in kidney and heart aluminum concentrations were observed only in animals with dental implants. No explanation for these decreases is evident. It is interesting to note that the aluminum concentrations obtained in lung

TABLE 1. TISSUE ALUMINUM CONCENTRATION IN BABOONS (ng/mL)

Tissue		Al_2O_3 Dental Implant	Control	Ti-6Al-4Va Bone Implant*	Control
Lung	X̄(N)	1576.27 (6)	133.15 (2)	1297.64	281.23
	SD	±129.26	± 1.3	± 31.76	±14.44
Lymph Node	X̄(N)	682.62 (6)	142.01 (2)	573.07	74.13
	SD	±196.67	± 4.09	± 26.91	± 4.15
Muscle	X̄(N)	239.19 (6)	157.12 (2)	345.16	139.43
	SD	±129.15	± 5.50	± 21.91	±10.47
Tongue	X̄(N)	1470.16 (6)	153.94 (2)	--	--
	SD	±234.46	± 2.70	--	--
Gingiva	X̄(N)	417.16 (5)	140.49 (2)	--	--
	SD	± 32.67	± 7.77	--	--
Brain	X̄(N)	118.15 (6)	125.33 (2)	--	--
	SD	± 4.37	± 2.47	--	--
Kidney	X̄(N)	119.92 (6)	163.36 (2)	101.97	108.40
	SD	± 5.79	± 9.84	± 9.85	± 7.23
Spleen	X̄(N)	122.48 (6)	124.82 (2)	179.31	214.40
	SD	± 6.19	± 2.46	±13.01	±19.09
Liver	X̄(N)	125.26 (6)	147.35 (2)	139.74	166.80
	SD	±13.05	± 3.89	±10.94	±12.96
Femur	X̄(N)	875.31 (6)	898.23 (2)	--	--
	SD	±83.16	± 2.03	--	--
Skin	X̄(N)	131.50 (4)	153.97 (2)	--	--
	SD	±11.71	± 15.35	--	--
Heart	X̄(N)	122.54 (6)	164.29 (2)	--	--
	SD	± 4.90	± 5.31	--	--
Stomach	X̄(N)	130.78 (6)	133.77 (2)	--	--
	SD	±16.17	±11.72	--	--
Thyroid	X̄(N)	129.86 (6)	133.00 (2)	--	--
	SD	±11.22	± 3.85	--	--
Pancreas	X̄(N)	123.00 (6)	134.05 (2)	--	--
	SD	± 9.65	±10.59	--	--

*Ti-6Al-4Va Data from Woodman et al.

X̄ = mean; (N) = Number of Animals; SD = Standard Deviation.

and lymph nodes of implanted animals are the same order of magnitude regardless of the source of the aluminum ion. Due to the dental implant study design, it was not possible to calculate a release rate. However, it is of interest to note that the Woodman study showed a zero order release rate of aluminum. This implies a continual release of aluminum not leveling off at any time. The consequence of this finding is unknown, but it should be recalled that no observable pathology attributable to the dental implants was indicated in any animal.

Clinical Studies

The clinical portion of this project has involved the implantation of rectangular ceramic roots in 60 patients. The clinical study commenced in August, 1978. The roots have been implanted using three different techniques. In the first 25 patients, roots were implanted in mandibular areas with the first (or uppermost) serration flush with the alveolar crest. This implant height was dictated by the post and core design, in which the gold overlaps the outside of the root structure and extends downward into the gingival sulcus. In the human, the implant was placed high enough to allow post and core seating without bone removal. Hence, the implant was placed higher than in baboon studies. Success in baboons, even when the implants were left to protrude slightly above the alveolar bone level, gave us confidence that in the "cooperative" human subject this procedure would be acceptable. In the first 25 patients, mandibular molar and premolar sites were used. Seventeen were healed sites and 8 were fresh extraction sites. All implants were periodically observed by clinical observation and x-ray. All implants were rigid at the time of surgery, by virtue of the interference fit produced by tapping the implant into place. All implants exhibited some degree of buccal-lingual mobility within the first 1 to 3 months post-implant. The degree of mobility and the cause of the increase in mobility was highly variable, but typically 1/2 mm or less mobility was observed within that time period. Sixteen of the 25 patients exhibited a subsequent decrease in mobility with time. Of the original patients, 8 are still in function with buccal-lingual mobility ranging from 0-3/4 mm. Six patients are unavailable for follow-up.

Consequently, the following data analysis should be viewed with caution. The average implant time for all patients is 5.12 years (5.59-4.75 years range). Within this group, 12 failures occurred in restored implants with a mean time to failure at 2.06 years (1-3.13 years range). Five unrestored implants failed at an average of 1.35 years post-implant (.04-2.25 years range). The apparent success rate for this group is 12-32 percent (3/25 or 8/25). In either case, this success rate is not satisfactory.

The typical failure process observed was a slow increase in mobility over two years. When mobility reached 1 mm buccal-lingual, with rotation present, the implant was removed to prevent unnecessary bone loss. Two patients had infection noted at implant removal time. Seven patients near removal time indicated some degree of soreness when biting hard. Generally gingival health remained excellent in all patients regardless of the state of failure. Most patients utilized the implants as functional and aesthetic devices up until the time of removal. Several patients had to be convinced of impending implant failure, since they were satisfied with the devices. All patients with implants removed have gone on to heal uneventually.

It is interesting to note that these statistics have not changed since last year with the exception of patients now not available for follow up. Consequently, the remaining implants in this group have reached an equilibrium state. There has been some loss in vertical bone height observed in patients, however, this is not a universal observation. Some patients appear to be uniquely free of bone loss. The patient data is being further evaluated with respect to bone loss.

In view of the difficulty of obtaining stability in the first group of patients, the next series of 6 patients (Group II) were performed using orthodontic devices to stabilize the implant to adjacent teeth. Orthodontic bands were fitted to adjacent teeth and connected by wires. An acrylic cap was fitted over the top of the implant to support and protect the implant.

The patients were implanted in the posterior mandibular areas, 5 in healed sites, and 1 fresh extraction site. The fresh extraction site implant never stabilized and was never restored. The implant was removed at 35 weeks post-surgery when rotation was observed.

Four of the healed site implants remain in function, but they all exhibit between 0.25 and 0.75 mm buccal-lingual mobility. The average implant time in this group is 3.73 years, with a range of 3.63 years to 3.84 years. The one functional failure in this group occurred after being implanted for 1.75 years and functional for 1.27 years. The overall success rate is 67 percent. Even though these implants are functional, aesthetic, and well accepted by the patients, they are less than optimal since there is some mobility. This group of implants continues to be of interest because there have been no additional losses despite the slight mobility in all implants. There appears to be some bone loss; however, the extent of the bone loss has not yet been quantitated. This group of patients has been more cooperative than Group I, and consequently, follow-up data are more reliable. The implants still in function remain in the same condition as described for two consecutive years.

A third group of patients (Group III) was started to assess if a deeper placement of the root would offer additional protection from mechanical "stress" and allow the initial mechanical stabilization of the implant to proceed to a long term rigid situation; as commonly observed in baboon studies, but infrequently observed in prior human studies. The implant design as utilized in Group I studies prevents flush placement of the implant. Since bone and attached gingiva would have to be removed to seat the overlapping post and core; the gold overlap (or coping) was removed, thus creating a post and core flush with the exterior surface of the alumina. Mechanical testing indicated that this removal of coping did not reduce the mechanical strength of the root-post and core attachment.[28] Consequently, post and cores for Group III studies do not have an overlapping gold coping. Additionally, the ceramic root portion has been modified to facilitate flush placement.

To date, 29 patients have been implanted in both fresh and healed sites using the flush implant technique (Group III). Fifteen implants have been placed in posterior mandibular areas and 14 have been placed in anterior maxillary areas.

The average implant time in this group is 1.79 $\pm$ .98 years (.37-3.05 years range). Eighteen of 29 or 62 percent of the implants remain.

The failures in this group have been predominantly in the mandibular areas. Three restored mandibular implants failed after an average implant

time of .89 years ± .19 years. Seven unrestored mandibular implants failed after an average of 1.06 years ± .06 years). One unrestored maxillary implant failed after an implant time of .72 years.

There are only three implants in this group that exhibit mobility. Consequently, there is less mobility in Group III than in Group II. Unfortunately, there is a subjective impression of bone loss. The amount of bone loss is presently being evaluated.

The human studies have presented a relatively stable picture over the last year. The losses have been minimal thus reinforcing the previous hypothesis that stated the initial stabilization of the dental implant is a critical step in long term success. The present data tend to substantiate that hypothesis. Group II and Group III implants appear to have potential success rates in the 60+ percent region. The Group I implant success rate is very poor but there have been no additional losses thus indicating that those implants successfully stabilized have a high probability for long term success.

Unfortunately, in all groups, the overall success rate is less than desired. However, this success and failure should be kept in context. The military objective of having an implant to fit a fresh extraction site dictated the use of the rectangular implant. This particular design constraint is thought to be a critical factor inhibiting initial ingrowth success and consequently limiting the long term successful outcome of the implants. Since a rectangular implant site is difficult to create in the bone, considerable bone growth is required before stabilization of the implant can be obtained as compared to a circular implant where a perfect hole to fit the implant can be created. Consequently, one would predict a higher long term success rate if a circular implant system were utilized. On the other hand, a circular implant system would be of little use in fresh extraction sites.

One disturbing factor noted in the study is the subjective impression of progressive bone loss. Both radiographs and periodontal probing data are presently being evaluated to assess the extent of the problem. The evaluation to date indicates that certain patients within our limited population might be immune to this loss of vertical bone height.

CONCLUSIONS

Last year's research has entailed a continued analysis of animal data from the highly successful baboon trials and a continuation of the clinical study. The most important finding continues to be the success rates for the human studies which are much less than those observed in baboons. However, the unique design constraints required for fresh extraction site implants are thought to partially account for the less than desired success rate.

The completed histopathologic analyses of the baboon data indicated no pathology that was attributed to the presence of dental implants. Pathology observed was primarily attributed to the aging process.

Atomic absorption mass spectrometry analysis of various body tissues from the baboons indicated increased concentrations of aluminum ion especially in the lung, regional lymph nodes, and tissues adjacent to the implants including bone, muscle tissue, and tongue. Since little is known of specific tissue levels of aluminum ion, the consequence of these elevated levels is unknown. However, it should be reiterated that no pathology was observed in the long term animal studies. Comparisons of aluminum concentration in various tissues were made to a companion study performed in baboons where titanium alloy implants containing aluminum were studied.

RECOMMENDATIONS

It is recommended that the human study be continued to ascertain if the increased apparent success observed with flush placement of the implants (Group III) can be continued. The maintenance of initial stability in a high percentage of this last group of implants is encouraging. Since initial stability appears to be a critical factor, techniques to facilitate initial stability should be incorporated. To this end, a regular shape (circular) implant should be considered to facilitate initial stabilization. The human implants should be closely studied to ascertain the extent and rate of bone loss. These studies should include an analysis of the sulcus flora.

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